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SCIENCE AND TECHNOLOGY ASSET MANAGEMENT: OPTIMIZING MULTI-PROGRAM MULTI-YEAR RESOURCE ALLOCATIONS

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(The views presented here are solely those of the authors and do not represent the views of the Office of Naval Research)

ABSTRACT

The Office of Naval Research (ONR) funds research that will benefit the U. S. Navy. In managing this research, ONR must allocate resources to achieve maximum benefits within its resource constraints. This report addresses one aspect of the resource allocation problem, namely, identifying funding profiles (normalized program funds as a function of time) for programs, or groups of programs, that provide maximum adherence to some predetermined policy.

Four examples are presented in this report. The first describes selection of an overall funding profile for a group of special programs called Accelerated Research Initiatives (ARIs). The profile was selected to ensure an infusion of new ARIs proportional to total budget, and the actual turnover of ARIs resulting from use of the profile is shown. The second example shows how, with the use of quadratic programming, additional constraints could be placed upon the funding profiles, if desired, and relatively stable ARI turnover would still result. The third example describes the use of quadratic programming in an experiment in which each member of a group of potential programs had maximum funding profile flexibility while obeying the group funding ceiling constraints. The fourth example describes an extension of the methodology of the third example that could be applied to determining the profiles of every program in any funding organization.

KEYWORDS: funding allocation; resource allocation; project selection; quadratic programming; operations research; program planning; budget forecasting.

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OVERALL FUNDING PROFILE FOR ACCELERATED RESEARCH INITIATIVES

A. Background

In 1981, ONR decided to devote a fraction of its total research budget to accelerated research programs (hereafter referred to as Accelerated Research Initiatives-ARIs). The objective of these ARIs was to concentrate resources into promising areas of research for a finite period of time in order to accelerate progress in the technical fields of the ARIs. The overall ARI program was to be increased in size until it achieved a target fraction of the total research budget, and then it would remain at approximately this (steady state) target level. The ARI selection process was designed to be competitive. Internal Navy organizations would submit proposals to ONR for these ARIs, and a fraction of these proposals would be funded (see Kostoff [1988] for a detailed description of this competitive process).

Initially, funding profiles for the individual ARIs were not specified by ONR and were at the discretion of the proposers. Consequently, the programs that won the competition for the first few years had a wide range of profiles, with the main ONR control being the first year's funds for each ARI. After the ARI programs had been in existence for about three years, projections for the annual pool of funds available for new ARIs (hereafter referred to as the margin) as a function of time showed that the margin would be highly oscillatory over time. It would range in amplitude from near-zero in some years to large amounts in other years. The desired policy was to have the annual infusion of new ARI funds proportional to the total ARI funds available, at least in the steady state phase following the initial transient startup. Therefore, the highly variable behavior of these funds in the steady state phase shown by the projections would have to be corrected. The ONR Planning and Assessment group initiated an analysis of the ARI funding dynamics to identify the causes of the margin oscillations and to specify funding profiles that would stabilize the margin to a target fraction of the ARI budget in each of several future years. The analysis that was performed follows.

B. Overview of Analysis

The margin is the difference between the total ARI component of the total ONR budget and the funds (obligations) for existing ARIs that result from past investments. The object of the analysis is to define ARI funding profiles such that the margin is a constant proportion of the total ARI budget at each point in time, at least in the steady state. Since in actuality the total ONR budget projections over time are uncertain, and thus the total ARI projections will be uncertain, it is unlikely that one profile can be found that would provide margin proportionality under a variety of growth assumptions. The approach taken will be to examine profiles that provide margin proportionality for a variety of possible budgets, and to identify those profiles that are most robust under a wide range of growth assumptions.

At any point in time t, the margin may be expressed as (using discrete notation):

$$M(t) = ARI(t) - \sum_{j=1}^{r} \left(M(t-j) * P(j+1) \right) \qquad (1)$$

where:

M(t) is the margin as a function of time t,
ARI(t) is the total ARI budget as a function of time,
r equals min(N-1, t-1),
N is the lifetime of an ARI,
P(j) is the funding profile for all the new ARIs installed as a margin over the life of these ARIs as a function of time j, and
SUM represents a summation over j.

Each element of the summation (M(t-j)*P(j+1)) represents obligated ARI funds to be spent at time t resulting from a margin (new ARIs) initiated at time (t-j) with funding profile P(j+1).

If the margins M(1), ...M(T) are known (where T represents the starting time from which future margins are projected), if C is the proportionality factor between margin and total ARI budget, and we wish to impose the conditions

$$M(t) = C * ARI(t), \quad t = T + 1, \ldots, T + N \qquad (2)$$

for the current year T, and N - 1 future years, then, by substituting (2) into (1), a system of N equations is obtained. The past margin values M(1), ..., M(T) are known, so if forecasts of ARI(t) are provided for t = T + 1, ..., T + N, (1) becomes a set of N linear equations in the N unknowns P(2), ..., P(N) and C, which can be solved for these variables. More details of the computations and the analysis can be found in Kostoff and Stanford [1989], and especially in Appendix 1.

1. <u>Linear Equation Approach</u>

In late 1984, projections of future margins were made using equations (1), the three most commonly used ARI profiles, and forecasts of total ARI funds. Use of a flat profile (constant funding over time) for each ARI predicted large amplitude oscillations for the total margin as a function of time, and these oscillations were not damped over multiple cycles. Use of the other profiles gave similarly large oscillations, with margins ranging anywhere from about $10M to almost $50M within the time span of a cycle. These unacceptably large oscillations would have to be remedied, in order to achieve the desired constant infusion of new ARIs.

The linear equations described in the previous paragraph were used to obtain profiles that would guarantee margin stability (i. e. relation (2)), for a set of annual ARI growth rates ranging from -1% to 96%. A large number of profiles were obtained, and seven were presented in Kostoff and Stanford [1989]. These were then tested to determine which single profile would provide the most stable margins over the entire range of realistic growth rates, consistent with funding stability requirements for sound program management. The profile selected had relatively low curvature. Within the first cycle of the margin projection, the oscillations are reduced substantially with use of this robust profile. As Kostoff and Stanford [1989] shows, the amplitudes of succeeding cycles are heavily damped. For all practical purposes, the oscillations are reduced to an acceptable level by the middle of the second cycle. This profile was provided to ARI proposers for POM years 1988-1991. The actual margin (with actual growth conditions) stabilized substantially with the robust profile, with an attendant ratio of margin to total ARI funds of approximately .22. Appendix 1 shows the detailed equations used to solve the problem, shows the profiles examined and actually used, and shows the stabilization of the margin profiles over time.

While the approach was developed for a specific problem faced by ONR, its application is very general. The problem of profile control of a large program composed of many sub-programs is endemic to all federal agencies, and other organizations as well. There are always new and special major programs being started, consisting of many sub-programs (e. g., Small Business Innovative Research, University Research Initiative, ARI, etc.). As shown in Kostoff and

Stanford [1989], and in Appendix 1, if the type of analysis presented above is performed before these programs are initiated, then instabilities in turnover funds can be prevented, and control over program management can be improved.

2. Quadratic Programming Approach

The procedures described in the previous section cannot accommodate bounds on the profile variables P(j). For example, several ARI proposers wanted to have the final year's funding, P(5), be at least 0.5 relative to the first year's funding at 1.0. To allow for the possibility of these, and other, inequality constraints, an optimization model was developed. The constraints included equations (1), which define the margin variables for a sequence of future time periods T + 1, T + 2, etc. Margins for $t \leq T$, and all ARI values, were specified via historical data or forecasts. Any bounds on the P(j), or on future margins, were also specified, and the objective assumed one of two forms:

$$\text{(a)}\quad OBJ = \sum_{t=T+1}^{tfinal} \left(M(t+1) - (M(t)\right)^2$$

$$\text{(b)}\quad OBJ = \sum_{t=T+1}^{tfinal} \left(M(t+1)/ARI(t+1) - M(t)/ARI(t)\right)^2$$

Objective (a) minimizes future margin fluctuations, while objective (b) keeps the ratio of margin to total ARI funds as stable as possible. Since all constraints are linear, either objective leads to a convex quadratic program, which can be solved by several NLP software systems. The authors used GINO [Liebman et. al., 1986] on an IBM AT, because GINO is easy to use and solves these problems very quickly. Some typical results follow.

Figure 1 contains four funding profiles, where the last year of each profile was set at a value of 0.5. The top profile was obtained from GINO runs using objective (a), and the next to top profile was obtained from GINO runs using objective (b). The next to the bottom profile is similar to the profile being used presently, with the exception that the profile value for the last year has increased from 0.3 (the base value of the present profile) to 0.5. The bottom profile is similar to the funding profile that had been optimized under conditions of zero growth (projected outward from FY1988), with the exception that the value of the profile's last year was increased to 0.5.

Figures 2 and 3 contain plots of the total ONR margins that were computed using the profiles of Figure 1 and the condition of zero total ARI growth. The total ONR margins that were computed with use of the GINO-generated profiles (Figure 2) have smaller fluctuations than the other two total ONR margins (Figure 3).

Figure 4 contains four funding profiles, where the last year of each profile was set at a value of 0.6. The top profile was obtained from GINO runs using objective (a), and the next to top profile was obtained from GINO runs using objective (b). The next to the bottom profile is similar to the profile being used presently, with the exception that the profile value for the last year has increased from 0.3 (the base value of the present profile) to 0.6. The bottom profile is similar to the funding profile that had been optimized under conditions of zero growth (projected outward from FY1988), with the exception that the value of the profile's last year was increased to 0.6.

Figures 5 and 6 contain plots of the total ONR margins that use the profiles of Figure 4 and the condition of zero total ARI growth. The total ONR margins that were computed with use of the GINO-generated profiles (Figure 5) have smaller fluctuations than the other two total ONR margins (Figure 6). The relative reduction in fluctuations between total ONR margins using GINO-generated profiles and the other two profiles is more pronounced in the case where the last profile year value was set equal to 0.6 than for the case where the last year of the present and zero growth profiles was set equal to 0.5.

Thus, a powerful tool has been developed to expand flexibility in specifying profiles while improving control of margin stability. It is projected that as more familiarity is gained by working with GINO, smoothing criteria and input of constraints can be improved and even stabler predicted margins will result.

TAILORING FUNDING PROFILES TO IMPROVE PROGRAM MANAGEABILITY

3. <u>Research Options Only Approach</u>

The use of GINO to obtain funding profiles that would minimize margin fluctuations in a least squares sense led to another class of applications involving the pre-ARI process. This process includes competitive evaluation of proposals known as Research Options (ROs) that, if successful, become ARIs. Circa 1989, each Research Option proposer was provided a recommended funding profile by his claimancy to be followed when submitting the RO. Since the total funding profiles for each claimancy are the same as the total ONR margin profile, to ensure that any combination of winning ROs will match the overall integral claimancy profile, each RO proposer is given essentially the same profile to follow. In the discussion to follow, this recommended profile will be called the MANDATED profile.

In early FY1988, a methodology was proposed by Kostoff [Hayles, 1987] that would allow each RO proposer to obtain a funding profile for his RO that would lie somewhere between the presently mandated profile and the profile that the RO proposer thinks would be best to manage his RO. In the discussion to follow, this latter profile will be called the DESIRED profile. While this proposed methodology appeared too late to be implemented for POM90 (the competition that occurred in Spring 1988), it was decided to run an experiment to see what RO profile improvements would have resulted if the process had been implemented for POM90. To provide data for this experiment, each RO proposer was asked to supply a five year desired RO funding profile that used the same total funds as the mandated profile. The following sections describe the experiment that was run, and the analysis and results as well.

The variables of the model, xij, are the dollar amounts allocated to RO i in year j. The constraints are of transportation form, specifying that the total allocated to each RO over its lifetime equal the total of its mandated profile, and that the total allocated to all ROs in each year equal the total funds available in that year. The objective is a weighted sum of squares of differences between the amounts allocated and the desired profiles. For POM90 there were 15 winning ROs, each with a five year lifetime. Hence the model has 5 * 15 = 75 variables and 5 + 15 = 20 linear constraints, plus nonnegativities. Typical runs using GINO with a cold start required about 30 minutes on an IBM PC-AT.

Appendix 2 displays the results. For each winning POM90 Research Option, the table gives the mandated, desired, and computed profiles, together with the absolute differences of (mandated -desired) and (computed - desired), for each year between FY90 and FY94. The SUM column provides five year totals for each RO, while the set of rows following RO 15 provides totals across all ROs. As shown in SUM column, the computed profile is closer to the desired one than the mandated profile for 10 of 15 ROs, sometimes by a factor of 3 or higher (for ROs 5,8,9, and 13). The TOTAL SUMMATIONS entries show that, over all ROs, the computed profiles come closer to those desired than the mandated profiles in each year, with a total 5 year difference of 9598 versus 12593, an overall improvement of about 25%. The largest improvements occur in FY90, 92, and 93, while 91 and 94 show little improvement.

Since the solver in GINO, GRG2, does not use sparse data structures, computing time on the AT increases rapidly with problem size. For the set of data discussed here, a 3 profile problem took 25 seconds, 6 profiles required 155 seconds, and 15 profiles required 1800 seconds. The GINO modeling language does not include indexing, which makes the entry of larger problems cumbersome. These difficulties have been remedied by recoding the problem in GAMS [Brooke, Kendrick, Meeraus, 1988], which has indexing capabilities and a sparse NLP solver, MINOS. Future experiments will include comparisons of the current quadratic objective with a sum of absolute differences objective, which can be minimized using linear programming. Also, future experiments will examine objectives that require that the computed profile for each RO be at least as close to the desired profile as is the mandated profile, or closer.

Thus, a unique tool is now available to increase flexibility of specifying funding profiles of individual sub-programs while obeying the funding ceiling constraints of the total program.

4. All Funded Programs Approach

The successful conduct of the experiment described above, and the experience gained in running the experiment, stimulated the final concept to be presented in this report. To provide the appropriate context for this concept, a program management structure typical of any federal funding agency will be described.

The hierarchical structure of a federal funding agency typically consists of a Director, perhaps 4 or 5 Associate Directors reporting to the Director, perhaps 3 or 4 Division Directors reporting to each Associate Director, and perhaps 3 or 4 Program Managers reporting to each Division Director. In some agencies, some of the hierarchy levels may be omitted, or new levels may be added (e. g., Program

Officers could report to the Program Managers).

At each level, similar funding allocation decisions are made. In all cases, there is a funding ceiling that each person is provided by his immediate manager (for DOD research, this is a five year ceiling projection), and there are many proposed tasks/ programs/ groups of programs of different total dollars and different possible funding profiles and different degrees of quality. Each person must decide how to allocate funds over time across projects. While the managers at each level in the hierarchy have a substantial amount of autonomy in the allocation of funds to the level immediately below them, nevertheless, the higher level managers do have approval authority on all funding allocations within their purview.

Assume for the moment that a manager in the hierarchy has decided which programs/ tasks he wants to fund in the level immediately below him. Assume further that he is required to make five year funding projections, and that he has decided on the five-year total funds for each of these programs/ tasks. For example, a program manager may have decided to fund 10 programs, with a specified total dollar value over five years for each of the ten programs. Then the method of the previous section could be used to allow the manager to select funding profiles that are optimal for program manageability within the constraints of the ceiling available to the manager.

However, this optimization must be viewed as a local, or sub, optimization, since it applies only to the area of responsibility of a specific manager. A more global optimization would occur if the next higher level manager included the two levels of the hierarchy below him in the optimization procedure. While the total funds for each program/ task would not change between the 'local' optimization case and the two-level more 'global' optimization case, the funding profile for each program/ task over the five years would probably be different under the two types of optimization. Extrapolating this procedure to its logical conclusion, the agency Director would have a tool for setting five year ceiling patterns for each of the subordinate hierarchical levels in an agency optimal fashion.

Thus, the agency optimization procedure could be envisioned to operate in the following manner. After much top-down bottom-up discussion, the agency Director would allocate funds to each of his or her Directorates as a five year total, and not specify the year-to-year funding. Directorate heads would in turn allocate funds to each of their Divisions as a five year total. This allocation recursion procedure would go to the task level. The managers at various levels would have the option of inserting profile constraints at any of the levels within their area of responsibility. For example, a Directorate head might want to place bounds on the year-by-year range of the five year funding pattern of each of his or her Divisions.

Then, an optimization would be performed in the spirit of the previous section, subject to the constraint of the five year funding profile that was provided to the agency. The resulting optimization would provide target five year funding patterns for each manager in the agency. This method essentially automates much of the trading among managers that is required to obtain better program manageability, but does the trading in a much more structured and comprehensive approach. The approach also offers the possibility of expansion if desired. For example, program quality could be incorporated in the objective function, either to weight the closeness of fit of the computer profile to the desired profile, or conceivably to help alter the amount of funds allocated to each program or task in addition to altering its profile.

FIGURES

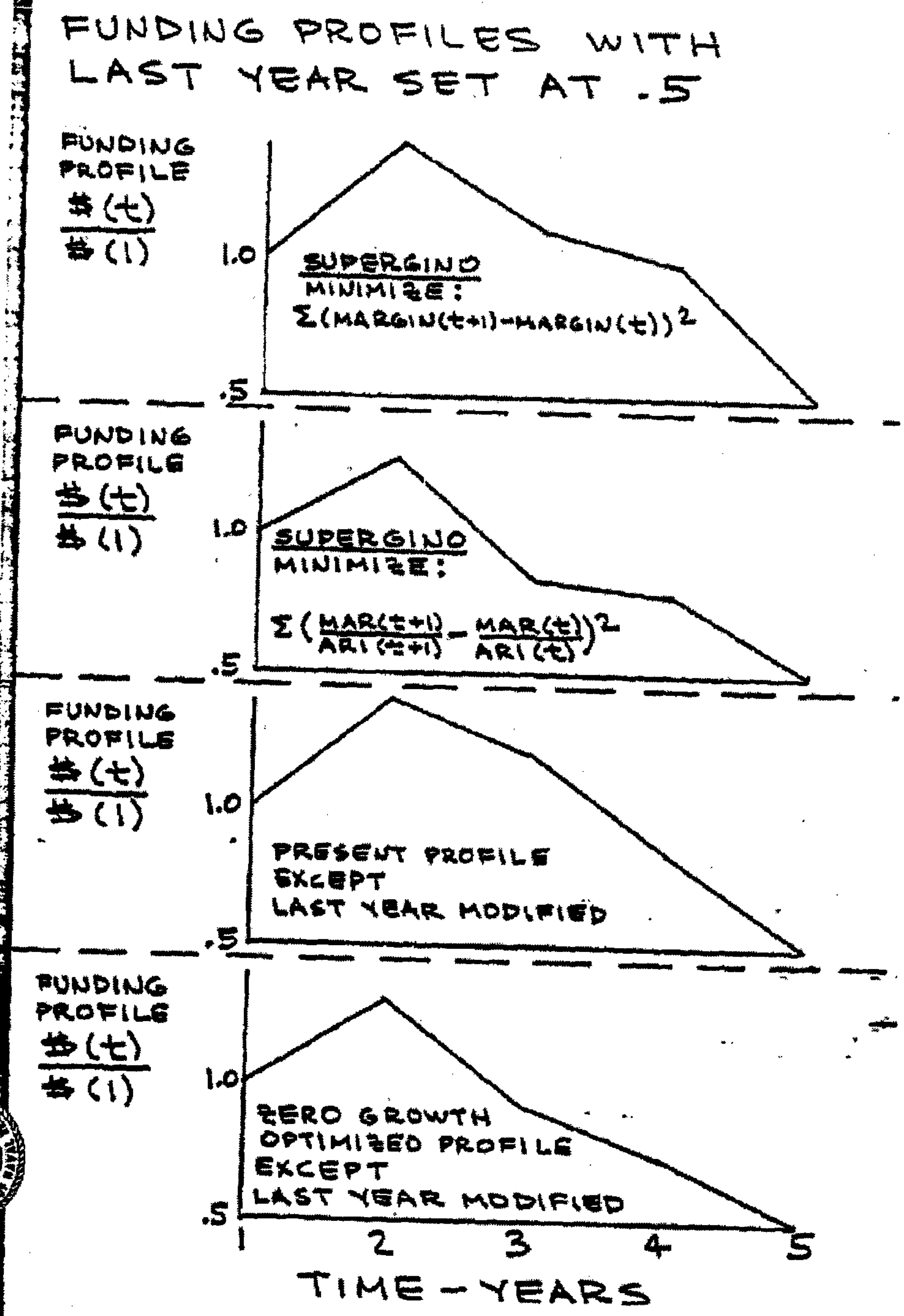
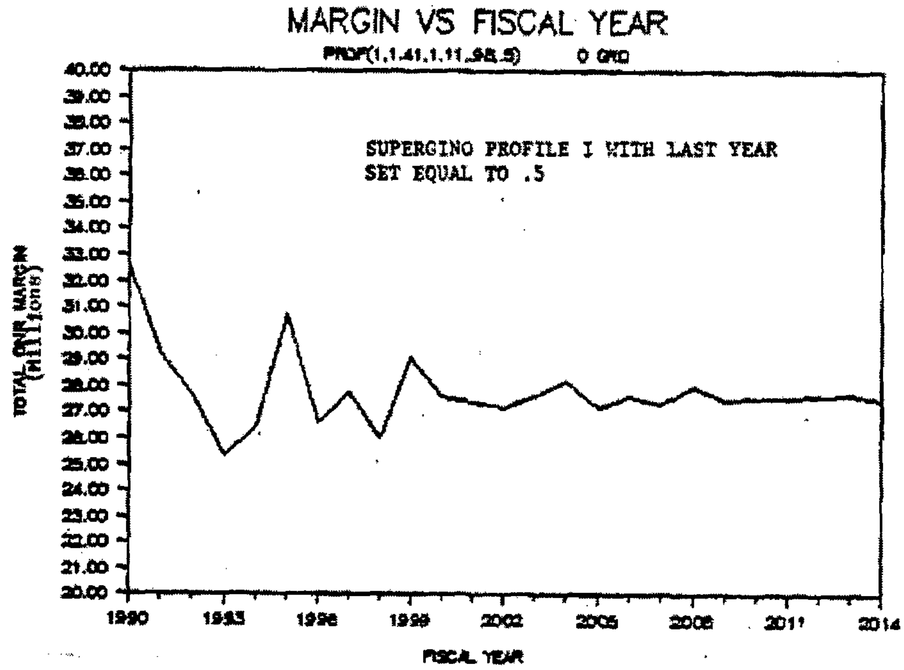


FIGURE 1


MARGIN VS FISCAL YEAR
PROF(1,1.41,1.11,.98,.5) 0 GRO
SUPERGINO PROFILE I WITH LAST YEAR
SET EQUAL TO .5
TOTAL OMIR MARGIN (Millions)
FISCAL YEAR

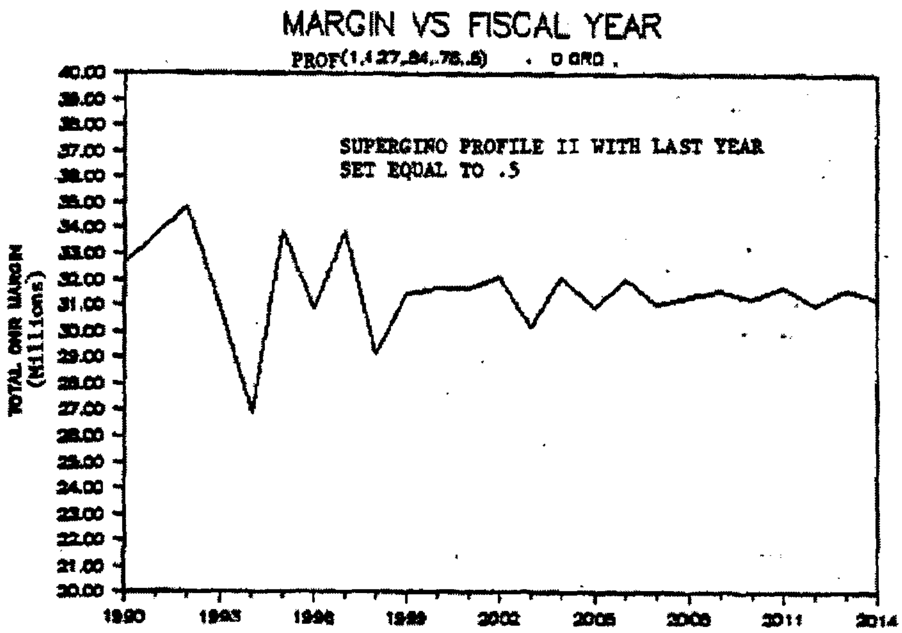
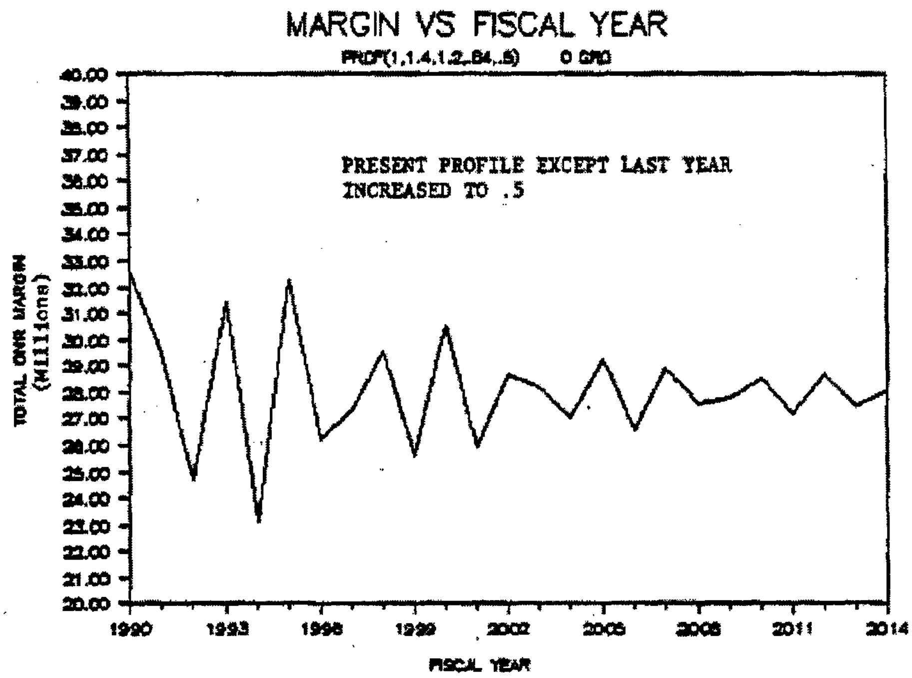

MARGIN VS FISCAL YEAR
PROF(1,4.27,.84,.76,.5) 0 GRO
SUPERGINO PROFILE II WITH LAST YEAR
SET EQUAL TO .5
TOTAL OMIR MARGIN (Millions)

FIGURE 2


MARGIN VS FISCAL YEAR
PRESENT PROFILE EXCEPT LAST YEAR
INCREASED TO .5
TOTAL ONR MARGIN
(Millions)
FISCAL YEAR

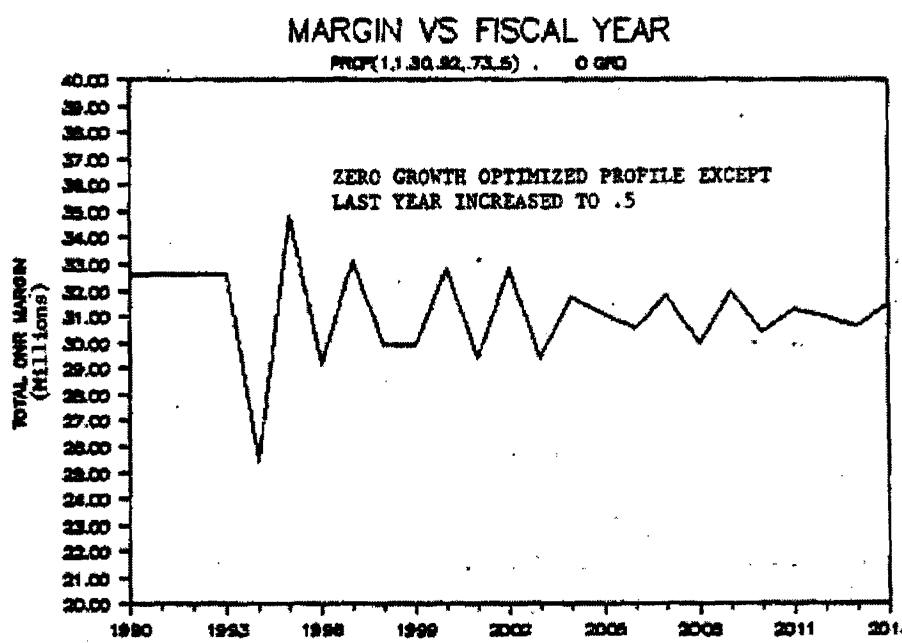
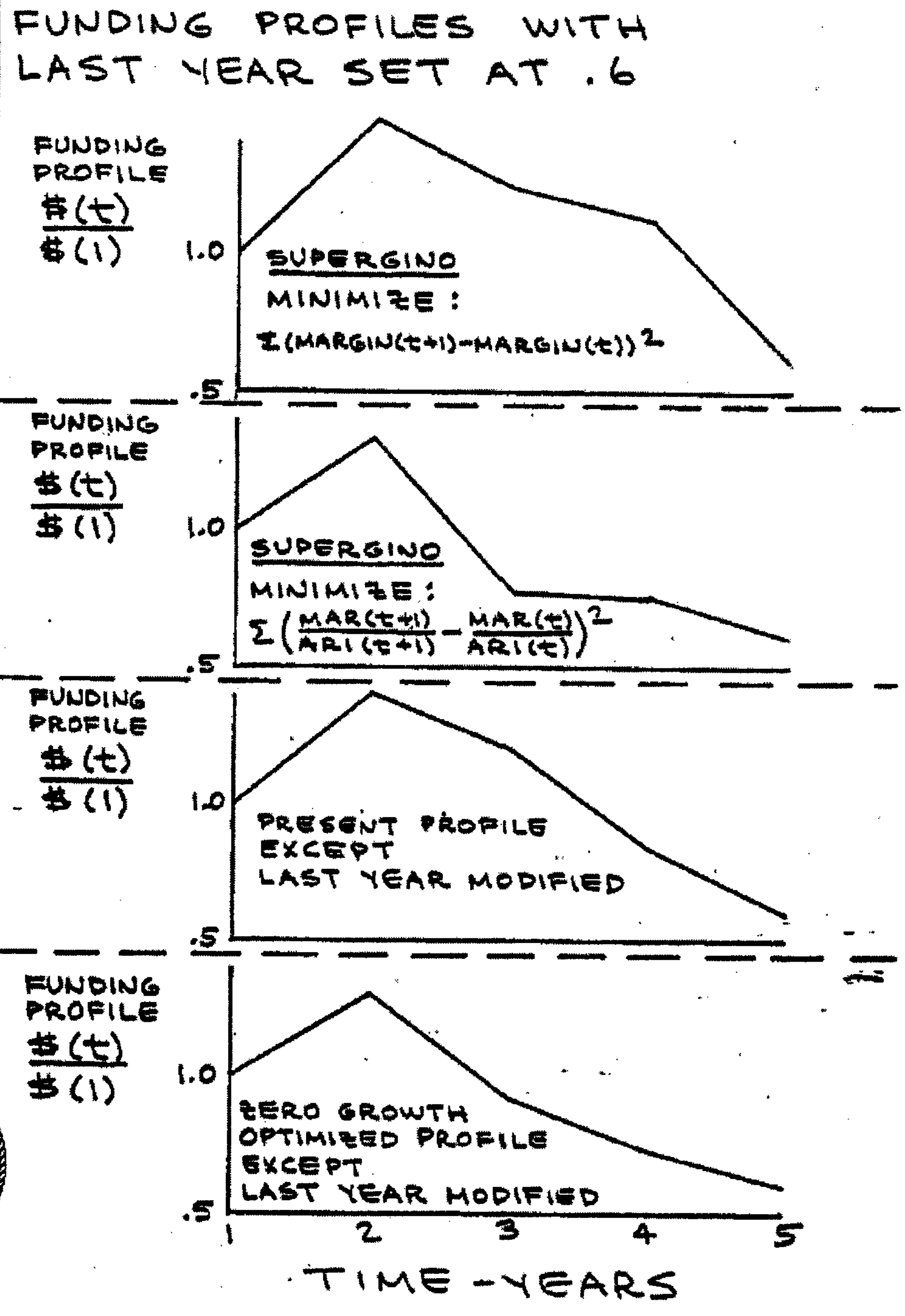

MARGIN VS FISCAL YEAR
ZERO GROWTH OPTIMIZED PROFILE EXCEPT
LAST YEAR INCREASED TO .5
TOTAL ONR MARGIN
(Millions)

FIGURE 3

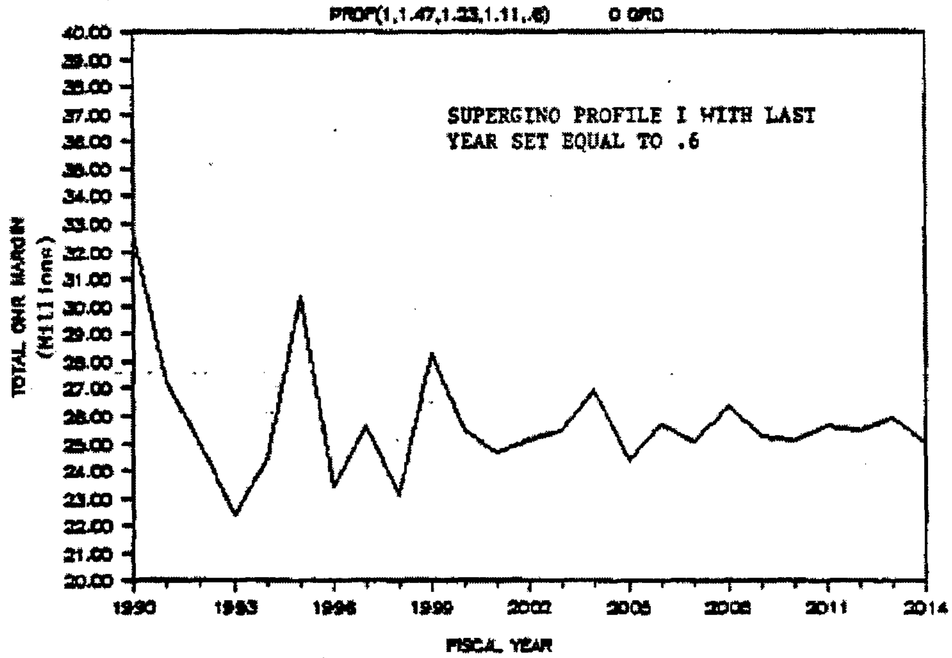


FUNDING PROFILES WITH LAST YEAR SET AT .6
FUNDING PROFILE
$\frac{\$(t)}{\$(1)}$
1.0
.5
SUPERGINO
MINIMIZE :
$\Sigma(MARGIN(t+1)-MARGIN(t))^2$
FUNDING PROFILE
$\frac{\$(t)}{\$(1)}$
1.0
.5
SUPERGINO
MINIMIZE :
$\Sigma\left(\frac{MAR(t+1)}{ARI(t+1)}-\frac{MAR(t)}{ARI(t)}\right)^2$
FUNDING PROFILE
$\frac{\$(t)}{\$(1)}$
1.0
.5
PRESENT PROFILE
EXCEPT
LAST YEAR MODIFIED
FUNDING PROFILE
$\frac{\$(t)}{\$(1)}$
1.0
.5
ZERO GROWTH
OPTIMIZED PROFILE
EXCEPT
LAST YEAR MODIFIED
1
2
3
4
5
TIME - YEARS

FIGURE 4

MARGIN VS FISCAL YEAR

PROF(1,1.47,1.23,1.11,.6)   0 GRO



MARGIN VS FISCAL YEAR

PROF(1,1.33,.77,.75,.6)   0 GRO

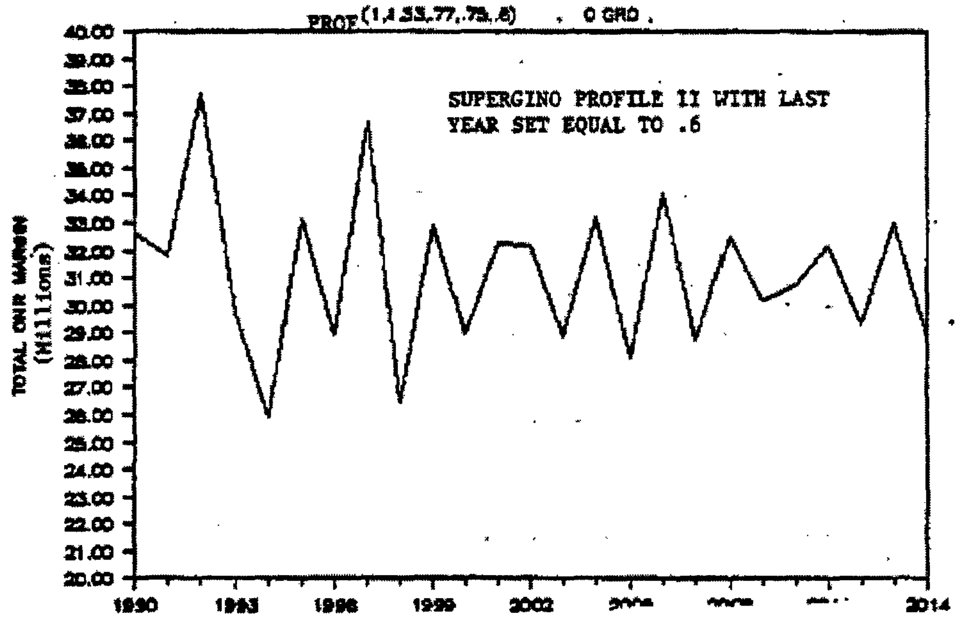
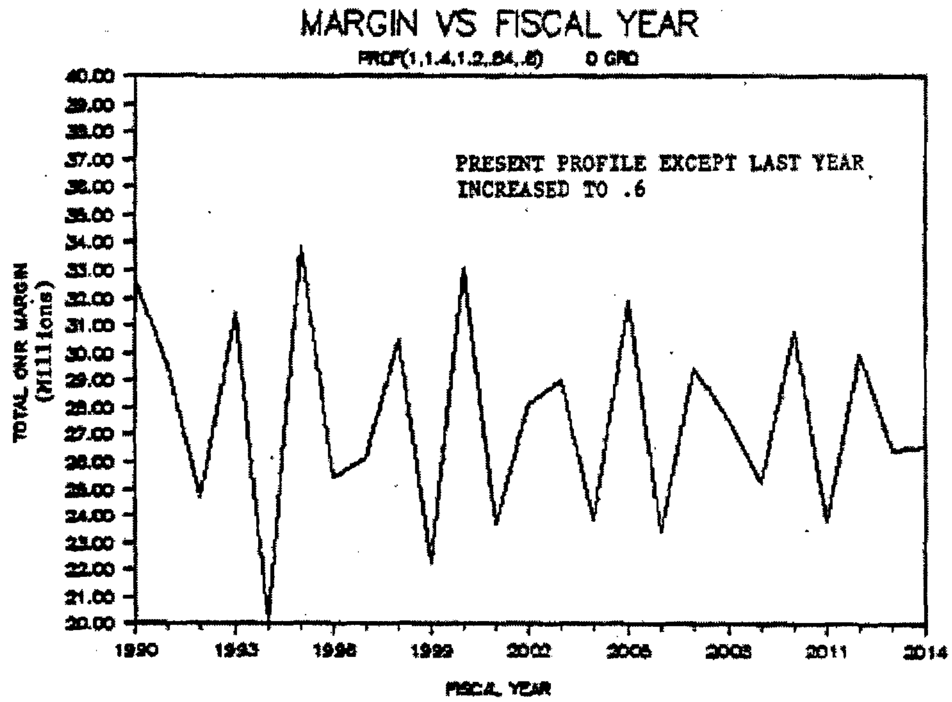


FIGURE 5


MARGIN VS FISCAL YEAR
PRESENT PROFILE EXCEPT LAST YEAR
INCREASED TO .6
TOTAL OMR MARGIN
(Millions)
1990
1993
1996
1999
2002
2005
2008
2011
2014
FISCAL YEAR

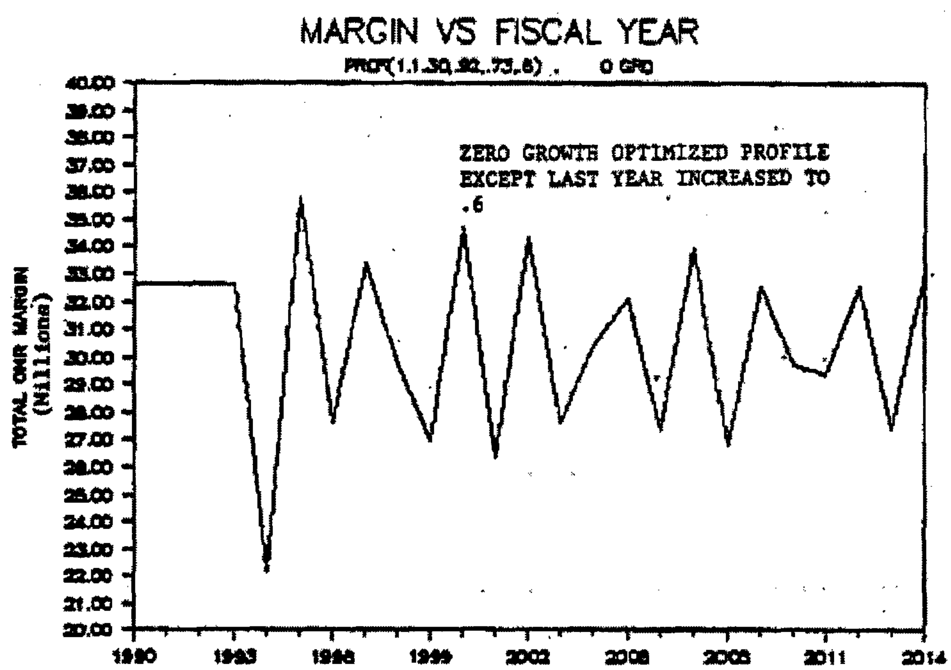

MARGIN VS FISCAL YEAR
ZERO GROWTH OPTIMIZED PROFILE
EXCEPT LAST YEAR INCREASED TO
.6
TOTAL OMR MARGIN
(Millions)
1990
1993
1996
1999
2002
2005
2008
2011
2014

FIGURE 6

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SUGGESTED FURTHER READING

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APPENDICES

APPENDIX 1 - FUNDING PROFILES UNDER BUDGETARY CONSTRAINTS

KEY WORD INDEX:

FUNDING PROFILE; PROGRAM PLANNING; ASSET MANAGEMENT; BUDGET FORECASTING; RESOURCE ALLOCATION

ABSTRACT

A method is developed to produce funding profiles of multi-year research programs under integral constraints driven by policy requirements and resource limitations. The integral equations which describe the dynamics of installed assets with finite lifetimes are solved for specified resource constraints, and funding profiles for multi-year programs are obtained. The robustness of different profiles is examined, and those profiles that are most robust under varying growth assumptions are identified. These profiles have been specified for new subprograms within an ongoing major program of Accelerated Research Initiatives conducted by the Office of Naval Research. Four years of data has shown that use of these profiles has achieved the desired targets, namely, allowing the infusion of new funds for these Accelerated Research Initiatives to be a constant fraction of the total Accelerated Research Initiative budget.

INTRODUCTION

A problem which occurs in many different fields of planning is that of asset management. In general terms, assets are installed, they are used for a finite time with specified life characteristics, and then they are taken out of service. These assets could be power plants, people, research programs, etc. The problem for the planner is to be able to predict the relationships between the detailed asset characteristics and their impact on resources, so that policies can be generated which will maximize appropriate figures of merit for the asset management process.

This paper addresses a subset of the asset management problem, where the assets are multi-year research projects which comprise a research program. It is desired to maintain a specific relationship among funding profiles for each research project **, research project lifetimes, and total program growth assumptions such that annual infusion of new projects will be a constant fraction of the total research program budget.

Before describing the specific problem which ONR encountered and solved using the technique which is described in this paper, a simple example will be presented which shows why the technique is important for asset managers. After the example, the background problems which led to the present analysis will be discussed. Then, the equations which describe the asset dynamics will be derived and solved for funding profiles, the predicted funds available for new programs with and without the 'optimal' profiles will be shown, and the actual funds which have been available for new programs for the four years in which the new profiles have been used will be shown.

**The funding profile for a multi-year research project is defined as the funds for each year of the project normalized to the funds for the first year of the project. Thus, a five year research project whose funds increase by ten percent each year would have the following funding profile: 1.00, 1.10, 1.21, 1.33, 1.46. The remainder of this paper will deal specifically with <u>margin</u> funding profiles, where the margin for a given year is the aggregate of all new projects installed in that year, and the margin funding profile is the composite profile for all the new projects. Thus, the funding profile for a multi-year margin is defined similarly as the funds for each year of the margin normalized to the funds for the first year of the margin.

IMPORTANCE OF FUNDING PROFILE CONTROL TECHNIQUE TO PROGRAM MANAGERS

The introduction of new programs should be planned ideally for minimum disruption of ongoing programs. New programs extending over several years, such as research or large asset construction, can encroach destructively on, or leave unwanted gaps in, future budgets, depending upon the funding profiles used for those new programs. Because the effects of these funding profiles on budget stability are not often obvious, it will be helpful to explore an example.

Assume that a program manager wants to start a new program consisting of a number of projects, each with a five year lifetime. The size of the new program will be too large to fund fully in its first year, so it will be installed with a relatively high growth rate trajectory during a buildup phase (say five years) and will continue beyond the buildup phase with a lower growth rate trajectory in a steady state phase. Thus, new projects will start each year (the number depending upon overall growth achieved), continue as more new projects are added in subsequent years, and be replaced after five years as continual program turnover is achieved. For many types of programs, it is very desirable to have this annual program turnover proportional to the total program funding in the steady state phase. This allows orderly planning and continuing renewal of vitality to the program.

Annual program turnover in the steady state phase of this example provides space for new projects, and is roughly equivalent to the margin for a given year (the margin being defined as the aggregate of all new projects installed in that year, and the margin funding profile as the composite profile for all the new projects).

If the program manager uses the method described in the present paper to specify the appropriate funding trajectory (the total program funds as a function of time) and profile combination <u>from the start of the program</u>, then the annual turnover will be proportional to the total program funding in the steady-state phase. With any other funding trajectory/ profile combination, the annual turnover fraction will fluctuate with time (in cases of severe fluctuations, some years a large fraction of total program funds would be available for new projects, and other years no funds would be available for new projects).

Alternatively, if the program manager uses the method described in the present paper to specify the funding trajectory and profile combination <u>after some initial arbitrary trajectory and funding profile combination has been employed</u>, then, in realistic situations, the annual turnover will approach proportionality to the total program funding in the steady-state phase after a period of about one or two project lifetimes.

A simple example will now be presented to illustrate the advantages of using the techniques developed in this paper and to show some types of fluctuations which can occur when the technique is not employed. Three cases will be presented.

In the first case, the program manager uses the method described in this paper to specify the total program funding trajectory/ funding profile combination which will yield an annual turnover proportional to the total program funding in the steady state phase. In the second case , the program manager uses the same total funding trajectory buildup as in the first case, but uses a different funding profile, which yields a fluctuating turnover/ total program funding ratio in the steady state phase. In the third case, the program manager utilizes another technique described in this paper (altering the funding profile at a later time) to remove the fluctuations in turnover ratio resulting from the second case. This latter technique was used to correct the turnover fluctuation ratio in the actual ONR application.

The parameter varied in the example will be margin funding profile, since for many cases this is the most readily controllable parameter. The margin for a given year is the aggregate of all new projects installed in that year, and the margin funding profile is the composite profile for all the new projects.

The following table shows the margin values (normalized to the predetermined total program funding) as a function of time for three different composite margin funding profiles. It uses the relationship that the margin at any point in time is equal to the total program budget at that point in time minus obligations at that point in time due to previously installed margins. It contains the assumptions of a five year buildup phase, zero percent steady growth rate, five year project and margin lifetime, and identical total program funding trajectories in buildup and steady state phases for all three cases.

TABLE 1

BUILDUP PHASE

	TIME	1	2	3	4	5
TOTAL ARI PROGRAM FUNDS	ARI	1.0	2.2	3.2	4.0	5.0
MARGIN1/ ARI RATIO	CAS1	1.0	.46	.31	.25	.20
MARGIN2/ ARI RATIO	CAS2	1.0	.64	.34	.13	.16
MARGIN3/ ARI RATIO	CAS3	1.0	.64	.34	.13	.16

STEADY STATE PHASE

TIME	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
ARI	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
CAS1	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20
CAS2	.22	.31	.22	.08	.12	.25	.37	.24	.02	.05	.28	.46	.27	.00	.00
CAS3	.22	.22	.22	.22	.22	.22	.22	.22	.22	.22	.22	.22	.22	.22	.22

The column heading, TIME, represents time from the program's start in years. Year 5 is the end of the buildup phase. The steady state phase examined ranged from year 6 to year 20.

The first data row, ARI, represents the total ARI program funding in $M. It was kept the same for all three cases examined.

The next data row, CAS1, represents the value of the margin (normalized to the pre-determined total program funding) as a function of time for the following five-year margin funding profile: 1,1.2,1,.8,1. The meaning of this profile is that if the margin for any year j were, say, $5M, then the outyear obligations resulting from this margin would be $6M for year j+1, $5M for year j+2, $4M for year j+3, and $5M for year j+4, and total obligations over five years would be $25M.

The margin values for CAS1 were obtained using the technique described later in this paper. The critical relationship (derived later in this paper) between the total program funding trajectory, the project lifetimes, and the margin composite profile was specified at the beginning to yield both the total program funding in the buildup phase and the margin in the steady state phase proportional to total program funding. As the results show, the margin after year five is a constant fraction, .20, of the total program funding. This means that every year, in the steady state phase, 20% of total program funds are available for new projects.

The next row, CAS2, represents the value of the normalized margin as a function of time for the following five-year margin funding profile: 1,.8,1,1.2,1. The margin values for CAS2 were obtained using the same funding trajectory and project lifetimes as the case for CAS1. The critical relationship specified for CAS1 was not utilized for CAS2. The sum of the five profile elements is the same as for CAS1 (5), which means that a $5M margin would result in the same total obligations over five years of $25M as CAS1, but with a different annual distribution.

These normalized margin values oscillate from .00 to .46 about a mean value of approximately .22 as a function of time, with a period of a margin lifetime (5 years). Thus, severe margin oscillations are possible even though the profile deviations are modest, and program planning and management become difficult in this case. As the body of this paper will show, the latter severe oscillations were the magnitude of oscillations projected by ONR in the early 1980s.

The last row, CAS3, represents the value of the normalized margin as a function of time for the following five-year margin funding profiles: In the first five years (the buildup phase), the profile used for newly installed margins was 1,.8,1,1.2,1, and in years six and beyond (the steady state phase), the profile used for newly installed margins was 1, 1.20, .92, .63, .73.

The margin values for CAS3 were obtained using the same funding trajectory and project lifetimes as in CAS1 and the same margin composite profile for the buildup phase as in CAS2. The profile for margins installed after the buildup phase was obtained using a technique developed later in this paper. Although the critical relationship specified for CAS1 was not utilized for CAS3, a new critical relationship was developed which would eliminate margin fluctuations in the steady state.

The margin in CAS3 is a constant fraction of total program funding in the steady state phase of .22, which means that 22% of the program will be turned over annually. Note that the steady state turnover fraction in this case, .22, differs from that in CAS1, .20, where the critical relationship was used at the program's initiation. The technique in CAS3, as will be shown in the following sections of this paper, was used to correct the major oscillations projected by ONR for its new programs.

BACKGROUND

In 1981, the Office of Naval Research decided to devote a fraction of its total research budget to accelerated research programs (hereafter referred to as Accelerated Research Initiatives - ARIs; while each ARI is referred to as a program within ONR, for purposes of this paper each ARI will be called a project, and the aggregate of ARIs will be referred to as the ARI program). The objective of these ARIs was to concentrate resources into promising areas of research for a finite period of time in order to accelerate progress in the technical fields of the ARIs. The overall ARI program was to be increased in size until it achieved a target fraction of the total research budget, and then it would remain at approximately this (steady state) target level.

The ARI selection process was designed to be competitive. Internal Navy organizations would submit proposals to ONR for these ARIs, and a fraction of these proposals would be funded. Initially, funding profiles for the individual ARIs were not specified by ONR and were at the discretion of the proposers. Consequently, the ARIs which won the competitions for the first few years had a wide range of profiles, with the main ONR control being the first year's funds for each ARI (See reference 1 for a detailed description of the ARI selection process).

After the ARI program had been in existence for about three years, projections showed that the annual pool of funds available for new ARIs (hereafter referred to as the margin) would be highly oscillatory over time, ranging in amplitude from near-zero in some years to large amounts in other years. Since the desired policy was to have the infusion of new ARI funds proportional to the total ARI funds available, at least in the steady state phase following the initial transient startup, the non-proportional behavior of these funds in the steady state phase shown by the projections would have to be corrected. The authors initiated an analysis of the ARI funding dynamics to identify the causes of the oscillations and to rectify the situation. The analysis that was performed follows.

ANALYSIS

Figure 1 contains generic budget trajectories for the variables of interest as a function of time. Curve A represents schematically the total ONR budget as a function of time t. Curve B represents the total ARI component of the ONR budget as a function of time t. The time range from t=1 to t=T is designated the buildup phase of the ARI budget, in which the ARI program is initiated at t=1 and reaches its steady state trajectory at t=T. In the steady state region (t > T), the total ARI funding is assumed to occupy a constant fraction of the total ONR budget.

The dashed curve labeled B' is the trajectory which results when the segment of curve B beyond time T (the steady state region) is extrapolated backward in time to t=1. This dashed curve will be utilized in the derivation of the necessary relationships among ARI margin funding profiles, ARI margin program lifetimes, and total ARI budget growth assumptions to produce margins proportional to total ARI funds in the steady state region. If the steady state region of Curve B is assumed to be steady growth (the ratio of ARI funds for any two adjacent years is constant), then the hybrid curve whose segment before T is B' and whose segment beyond T is B represents a hypothetical steady growth curve from t=1 to the far future for the total ARI budget.

Curve C represents obligations at time t resulting from ARIs which were installed at times less than t and are still ongoing projects. The margin at time t, designated on Figure 1 as M(t), is the difference between Curve B and Curve C, and represents the available pool of funds for all new ARIs initiated at time t.

The object of the analysis is to define the relationships among ARI margin funding profiles, ARI lifetimes, and total ARI growth projections which will result in margins which are a constant proportion of the total ARI budget at each point in time, at least in the steady state. The analysis will include conditions where the critical relationships among these parameters were established at the start of the program, and the margin was proportional to total ARI funding throughout the steady state phase, as well as conditions where the critical relationships among these parameters were established during the buildup phase of the program, and the margin approached proportionality to total ARI funding at some point within the steady state phase.

Once the critical relationships among these parameters for producing margins proportional to total ONR budget are obtained, the next pragmatic step is to modify the most easily controllable parameters to produce the desired margins. In the ONR case described in this paper, the parameter modified most easily was the ARI margin funding profile, and most of the present paper will describe techniques used to identify margin profiles which will result in margins proportional to total ARI funding.

Since in actuality the total ONR budget projections over time are uncertain, and thus the total ARI projections will be uncertain, it is unlikely that one margin profile can be found which would provide margin proportionality under a variety of growth assumptions. The approach taken will be to examine profiles which provide margin proportionality for a variety of possible budgets, and to identify those profiles which are most robust under a wide range of growth assumptions.

At any point in time t, the margin may be expressed as (using discrete notation, and the convention that a single asterisk * represents multiplication, and a double asterisk ** represents raising to a power):

$$M(t) = ARI(t) - \sum_{j=1}^{t-1} \left(M(t-j) * P(j+1) \right) \quad , \; t<N \tag{1}$$

$$M(t) = ARI(t) - \sum_{j=1}^{N-1} \left(M(t-j) * P(j+1) \right) \quad , \; t>=N$$

where :

M(t) is the margin as a function of time t and is the total of all new ARIs which will be installed at time t;

ARI(t) is the ARI budget as a function of time t and represents the total expenditures for existing ARIs at time t;

P(j) is the funding profile for the margin installed at time j (aggregrated over the funding profiles of all new ARIs installed at time j), and represents the funds for each year of the margin normalized to the funds for the first year of the margin. P(j) is zero for j<1 and for j>N;

j is a dummy variable which ranges from 1 to N when t>=N, and ranges from 1 to t when t<N;

SUM represents a summation over j.

Each element of the summation (M(t-j)*P(j+1)) represents obligated ARI funds to be spent at time t resulting from a margin (new ARIs) initiated at time (t-j) with composite funding profile P(j).

Two cases will be examined:

1) where the margin funding profile P(j) was specified at the beginning of the buildup phase (the period of time between establishment of the ARI program and achievement of its target fraction of the total ONR budget) to provide a margin proportional to total ARI funds in the steady state after the buildup phase and

2) where a margin funding profile P(j) was not specified at the beginning of the buildup phase to provide a margin proportional to total ARI funds in the steady state.

Case 1) - Margin funding profile specified in buildup phase.

The purpose of the derivation in this section is to show that the total ARI trajectory (in the buildup phase) which has been constructed from margins based on a hypothetical steady growth curve (in the buildup phase) will mesh smoothly with the desired steady state growth curve at the end of the buildup phase. The derivation starts by relating the total ARI budget to the margin on a steady growth path (a trajectory whose annual increase is the growth rate g). On this steady growth path, the ratio of margins or total ARI budgets for any two consecutive years is:

$$M(t + 1)/ M(t) = 1 + g \qquad (2)$$

Combine equations (1) and (2), to get

$$ARI(t) = M(t) * (1 + \sum_{j=1}^{N-1} (P(j+1)/ ((1+g)^{**}(j)))) \qquad (3)$$

If, during the ARI program buildup phase (t=1 to t=T), curve B' (the virtual steady growth path) were used to determine the value of the margin in the buildup phase, then at the end of the buildup phase T, the total ARI budget would be related to the margin by equation (3), and the following relationships would also exist:

$$ARI(T) = ARI(1) * (1 + g)^{**}(T-1) \qquad (4)$$

$$M(T) = M(1) * (1 + g)^{**}(T-1) \qquad (5)$$

Thus, curve B, which has been constructed in this case from the margins defined by equation (3), would have a total ARI budget at the end of the buildup phase (t=T) described by:

$$ARI(T) = M(1) * (1+g)^{**}(T-1) * (1 + \sum_{j=1}^{N-1} (P(j+1)/ ((1+g)^{**}(j)))) \qquad (6)$$

Equations (6) and (3) are combined, to yield:

$$ARI(T) = ARI(1) * ((1 + g)^{**}(T-1)) \qquad (7)$$

Thus, the relationship between total ARI budget at the end of the buildup phase and at the beginning of the buildup phase, as described by equation (7), is identical to that which would have obtained proceeding along the steady growth curve B'(equation 4), and therefore use of the margins described by equation (3) will result in the buildup phase trajectory meshing smoothly into the steady growth trajectory at the end of the buildup phase. Moreover, using the margins of equation (3) will allow the steady growth trajectories for total ARI budget and margin to be followed after the buildup phase, and the margin will be proportional to total ARI budget in this steady growth phase. The proportionality factor between total ARI budget and margin, as shown by equation (3), is a function of profile P, ARI margin life N, and growth factor g.

The important conclusion to be drawn from this derivation is that when generating a new program (or any type of asset installation process) in which a relatively stable turnover is required eventually and in which large transient oscillations are undesirable, the initial buildup trajectory cannot be specified arbitrarily, but rather must be related to the program (asset) life, funding profile, and growth assumptions in a precise manner.

Case 2) - Arbitrary margin funding profile in buildup phase

The purpose of the derivation in this section is to show that in the case where the critical relationships among funding profile, margin, and total ARI budget defined in Case 1 are not used in the buildup phase, it is still possible to determine margin funding profiles for ARIs installed in the future such that the future margins will be proportional to future total ARI funds. If the critical relationships among funding profile, margin, and total ARI budget defined in Case 1 are not used from the beginning of the buildup phase, it is highly unlikely that the margin will be proportional to total ARI funds in the steady state.

Before the present analysis was initiated by the authors, the requisite margin/ funding profile/ total ARI funds relationship defined in Case 1 had not been used by ONR. Margin projections by the authors immediately prior to this analysis showed highly non-proportional behavior between future margin and total ARI funds. The method which follows is the one that corrected the oscillatory margin behaviour and was implemented in ONR.

Assume that at the end of the ARI buildup phase, it is desired to specify a margin funding profile for new ARI programs such that in the future the margin will be proportional to total ARI funds. The basic dynamical relationship among margin, ARI margin funding profile, and total ARI funds remains as before, and a system of simultaneous equations which are of the form of equation (1) must be solved.

Solution of these equations will be more complicated than for Case 1). The margin funding profile for ARIs installed after the buildup phase, P1(j), will be different from the margin funding profile for ARIs installed during the buildup phase ,P(j).

To solve for margin funding profiles for new ARIs which will allow future margins to be proportional to total ARI funds, write an equation in the form of equation (1) for each t in the interval of the lifetime of an ARI margin installed at the end of the buildup phase (t=T+1, T+2,..,T+N). Add the assumption that the margin M(t) is proportional to total ARI funding ARI(t) in the region of time after the end of the buildup phase (M(t)=Q*ARI(t), t>T, where Q is a constant), and solve this system of equations simultaneously.

In the actual ONR situation, where each margin had a nominal five year lifetime and there had been a five year buildup phase, equations in the form of equation (1) were written for integer values of t ranging from 6 to 10. This produced five equations with five unknowns. Simultaneous solution of these five equations yielded the proportionality factor Q between margin and total ARI funding after the buildup phase, and the remaining future margin funding profile vector elements P1(2), P1(3), P1(4), and P1(5).

The profiles obtained by solution of these equations will, for purposes of this paper, be called 'optimal' profiles. Since P1(2), P1(3), P1(4), and P1(5) are relative values (normalized on the first year's margin value), with P1(1) being unity, solution of these equations in tandem with a specified total ARI funding trajectory specifies the margin and the ARI program in dollars.

The above solution yields only those profiles which provide a margin exactly proportional to total ARI funds. If sensitivity studies are desired, where the impact of 'non-optimal' profiles on the margin variation with time could be observed, then the system of equations of the form of equation (1) would have to be solved differently.

In this simpler case, a known profile is inserted into the same series of equations as above. However, the equations are not solved simultaneously. They are solved sequentially (each equation has only one unknown), and the resulting margin is tracked in time.

RESULTS

First, the unstable margins projected before the 'optimal' profiles were obtained and before sensitivity studies were performed will be discussed. It was these highly oscillatory margins which led to the analysis. Then the margins and profiles resulting from the analysis will be described.

In late September 1984, data from previously-installed ARIs, in combination with total ONR budget projections, were used to predict future margins. Since no single profile was being used by the different proposers, margin projections were made using the most common funding profiles either in use at that time or being proposed by management at that time. Figure 2 shows the three most commonly used and discussed profiles. Use of these three profiles resulted in the margins shown in Figure 3 under conditions of zero total ARI funds growth and six per cent growth. Large margin oscillations are evident. Many other profiles were run and, while the specific patterns varied, the end result was always unacceptably large oscillations.

The method of solution described in Case 2) above was used to obtain 'optimal' margin funding profiles which would produce margins proportional to total ARI funding in the steady state phase. Using the existing data from previously-installed ARIs and projection of total ARI funds (as of September 1984) as described above, computer runs were made for a large number of growth rates. The 'optimal' margin profiles obtained (parameterized on growth rate) are shown in Figure 4. Then, the robustness (sensitivity of the margin projections to profile perturbations) of the profiles was examined.

Figures 5A, B, C contain plots of projected margins as a function of time for three margin profiles using two different total ARI funding growth rates. In Figure 5A, the profile used is that which gave a margin proportional to total ARI funding for zero per cent growth. In the top curve of Figure 5A, which is parameterized at zero per cent growth, the margin is by design steady with time. In the bottom curve of Figure 5A, (six per cent growth), the margin experiences sizeable oscillations initially, and these grow until they become very unstable. One characteristic of the profile used in 5A is that for growth rates of even less than one per cent, very unstable margins resulted. Also, when profiles which were obtained for growth rates of less than one per cent were run for growth rates of zero per cent, very unstable margins resulted.

A more graphic description of this instability to minor perturbations is shown on Figure 6, where only the value of the peak point of the profile used in 5A was varied and the resultant effects on the margin stability were studied. The ordinate represents the time at which some measure of margin instability exceeds an arbitrary threshold value, and the abscissa represents the percentage increase of the value of the peak point of the profile above its 'optimal' value. The ordinate units are years after the new profile is utilized, and the abscissa units are taken to the base 2. Thus, the abscissa point of -3 represents an increase in the profile peak point of (2**(-3)), or 1/8, per cent (0.125 %). The upper curve represents the first year in which the margin goes to zero, the middle curve represents the first year the margin varies by 10% or more, and the bottom curve represents the first year the margin varies by 5% or more. Thus, the margin eventually becomes unstable even for the smallest perturbations, although the time to instability increases as the perturbation decreases. Similar curves were obtained when the value of the peak profile point was decreased from the 'optimal' value. High curvature profiles such as the one used in Figure 5A are not robust and result in very sensitive margins which go unstable at the slightest perturbation from their design point.

In Figure 5B, the profile used is that which gave margin proportional to total ARI funding for twelve per cent growth. In the top curve of Figure 5B (zero per cent growth), the margin experiences mild oscillations initially, but these appear to damp out with time. In the bottom curve of Figure 5B (six per cent growth), the oscillations again appear to damp out with time.

In Figure 5C, the profile used is that which gave margin proportional to total ARI funding for twenty four per cent growth. In the top curve of Figure 5C (zero per cent growth), after very few mild initial transients, the margin becomes very steady. The same statement can be made for the curve on the bottom of Figure 5C (six per cent growth).

Figure 7 contains a tabular summary of margin stability for most of the profiles from Figure 4 at different growth rates. Starting from the top profile on Figure 4 (-1 per cent growth), the margin stability improves going toward the profiles obtained at the higher growth rates.

The three profiles from Figures 5A, B, C were run under a large variety of conditions in which the growth rate was perturbed, including sinusoidal and impulsive perturbations. The results were always consistent. The profile obtained for twenty four per cent growth always exhibited much stronger margin damping than the other profiles, similar to the results of Figures 5A, B, C.
Perhaps fifty other arbitrarily-defined profiles were examined to see whether they had margin damping characteristics superior to those of the low curvature profiles of Figure 4. Over a range of growth rates, none performed as well as the low curvature profile of Figure 5C.

This low curvature profile was modified slightly to provide more funding in the last year, and was the profile recommended to the proposers. This low curvature profile has been recommended to the proposers for four years, and the proposers have complied with the recommended profile quite well. The margin history since the new profile was installed is shown on Figure 8, and the margin fraction of total ARI funds is shown on Figure 9. Three cases are compared on both Figures 8 and 9.

The circles represent the margin projections (made in 1984) using a flat profile and assuming the total ARI funds remained constant in the future. The squares represent the margin projections (made in 1984) using the profile recommended to the proposers and assuming the total ARI funds remained constant. The triangles represent the margin history since the new profiles were used, and the total ARI funds were those actually expended.

While Figure 5C shows that one complete ARI cycle is required before the margin oscillations are fully damped using the recommended profile, Figures 8 and 9 show significant margin damping well within the first ARI cycle for the recommended profile relative to the flat profile. The actual margin damping appears slightly better than the projected damping. In fact, the margin fraction has attained the desired predicted value and appears to have stabilized, despite the variation in growth rate which the total ARI program has experienced since the initial studies were performed (including changing the ARI fraction of total program funds), and the variation in profile of the embedded ARI programs due to continual budget modifications.

Because the major sources of instability to future margins have been removed by using the new profile, other funding profiles, whose previous use would have destabilized future margins, can now be considered for future use. In particular, profiles with a lower second year peak and higher final year value, which may be advantageous for some types of programs, are now being examined.

SUMMARY AND CONCLUSIONS

Since 1981, ONR has devoted a fraction of its budget to accelerated research initiatives. When these ARIs were installed initially, they had a diversity of lifetime funding profiles, and thus the early margins had a diversity of funding profiles. The consequence was that the projected annual infusion of new funds for these accelerated initiatives oscillated severely over time.

An analysis of the funding dynamics was performed, and the oscillations were shown to be due to the lack of constraints placed on the funding profiles. The analysis showed further that if it were desired for the annual infusion of new funds for these accelerated programs to be proportional to the total ONR budget, then profiles could be obtained by an inversion procedure which would damp out the projected oscillations and result in a stable infusion of new funds.

A large number of profiles was obtained from the inversion procedure under different environmental conditions and from arbitrary specification as well, and the impact of these profiles on the stability of the infusion of new funds was examined. The low curvature profile which proved to be the most robust of these profiles was recommended to the accelerated initiative proposers, and the proposed and eventually funded ARIs have utilized this 'optimal' profile for four years. Both actual and projected infusions of new funds for these accelerated initiatives have proved to be very stable, as projected initially. The methodology developed is general, and could be applied to any type of asset management problem in which assets are installed, are used for a finite period with specified characteristics, and then are taken out of service.

REFERENCES

1. Kostoff, Ronald N., "Evaluation of Proposed and Existing Accelerated Research Programs by the Office of Naval Research", IEEE Transactions on Engineering Management, November 1988.

BUDGET TRAJECTORIES OVER TIME

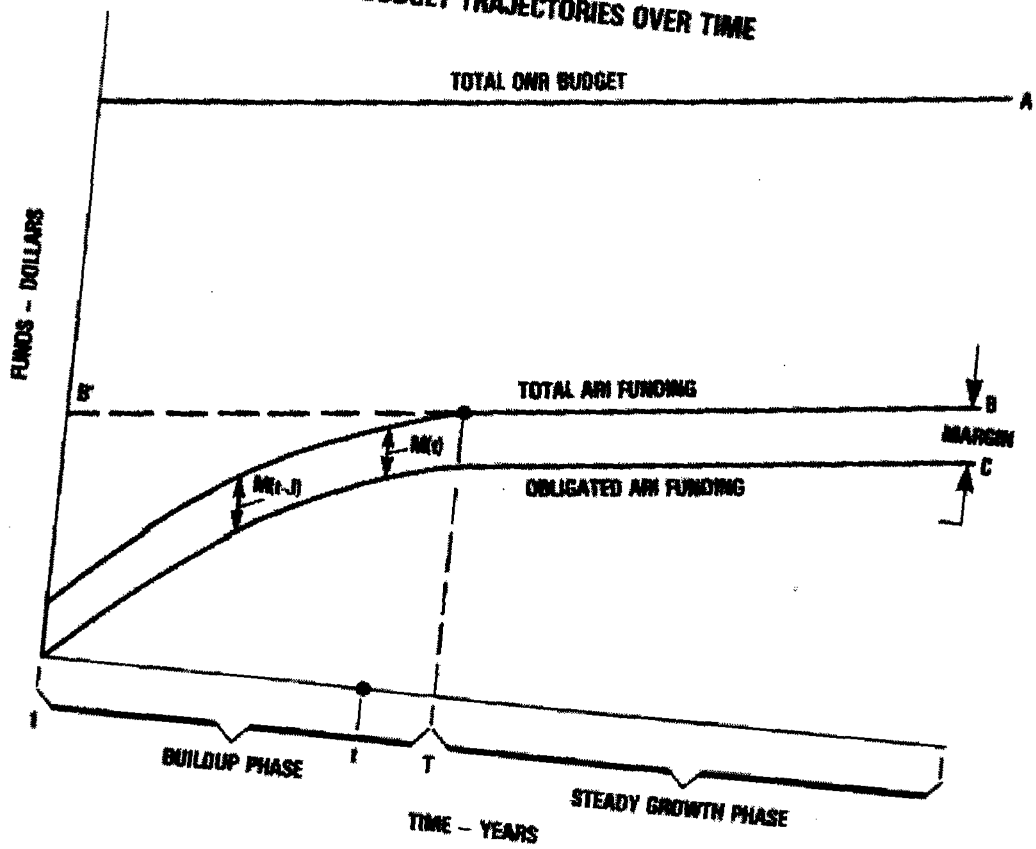


FIGURE 1

COMMONLY USED FUNDING PROFILES

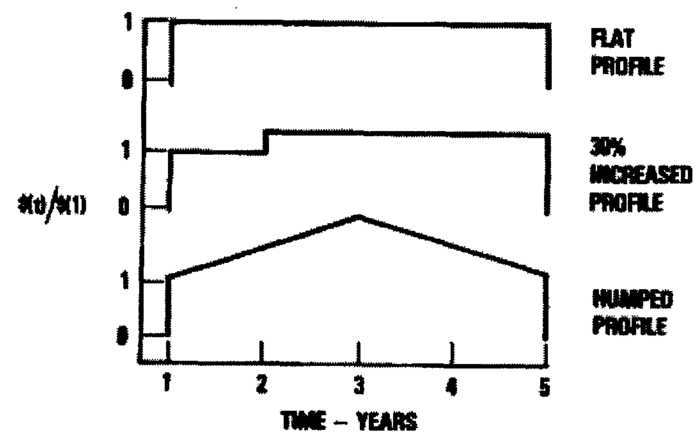


FIGURE 2

IMPACT OF COMMONLY USED FUNDING PROFILES ON MARGIN PREDICTIONS

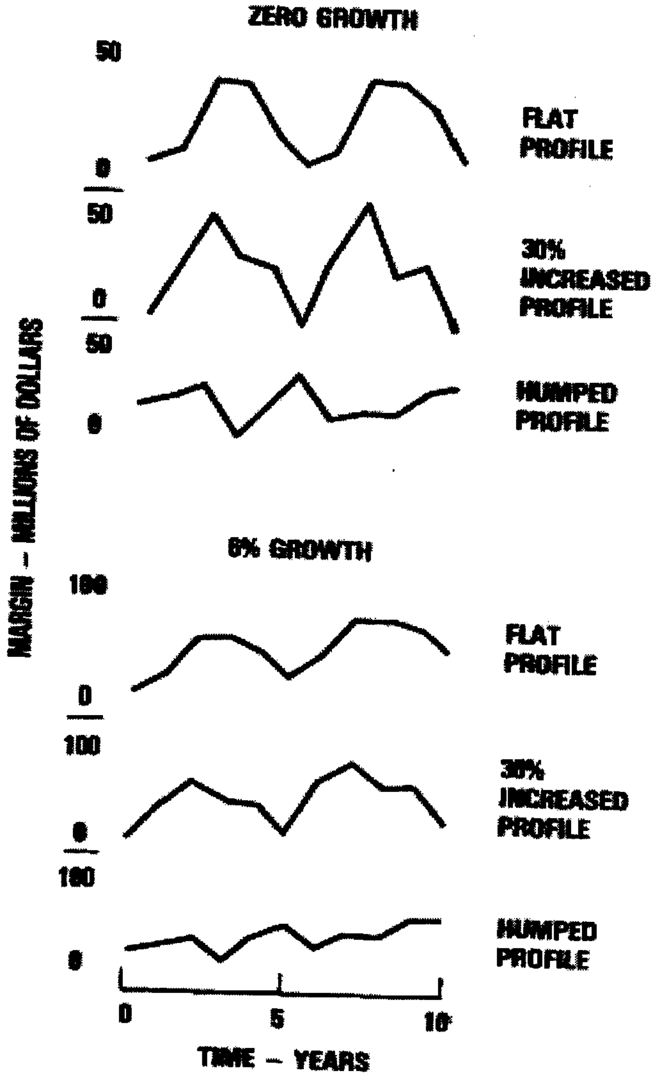


FIGURE 3

'OPTIMAL' FUNDING PROFILES

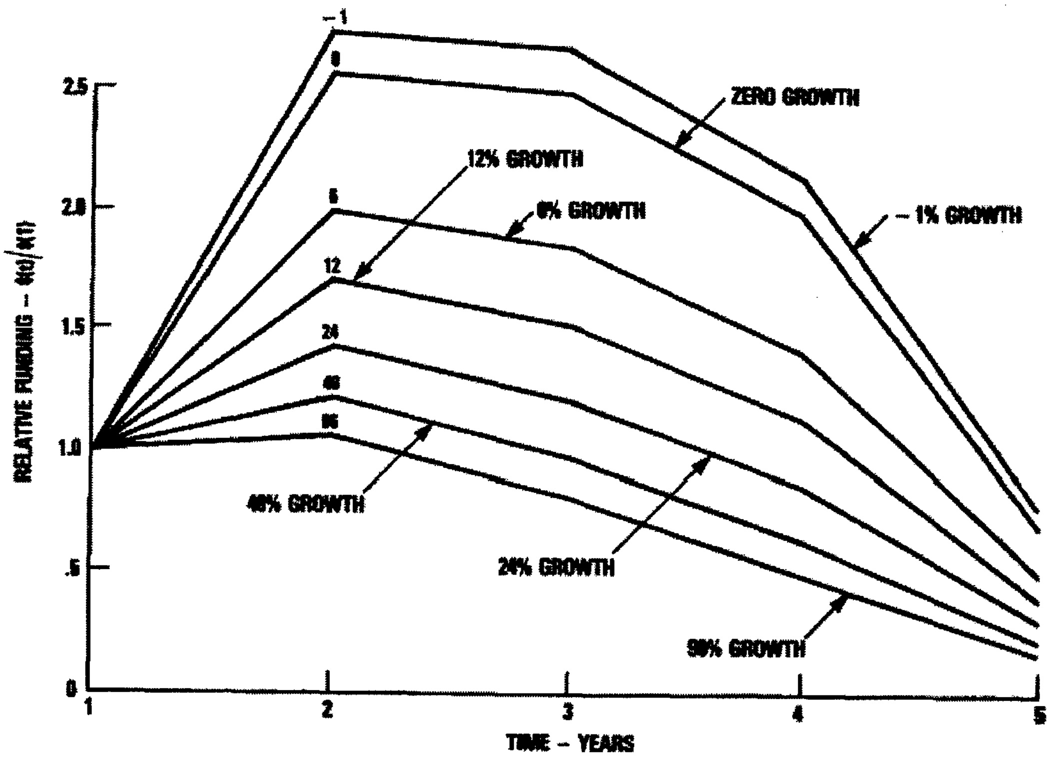


FIGURE 4

PROJECTED MARGINS VS TIME

PROFILE OPTIMIZED FOR ZERO GROWTH

FIGURE 6A

PROFILE OPTIMIZED FOR 12% GROWTH

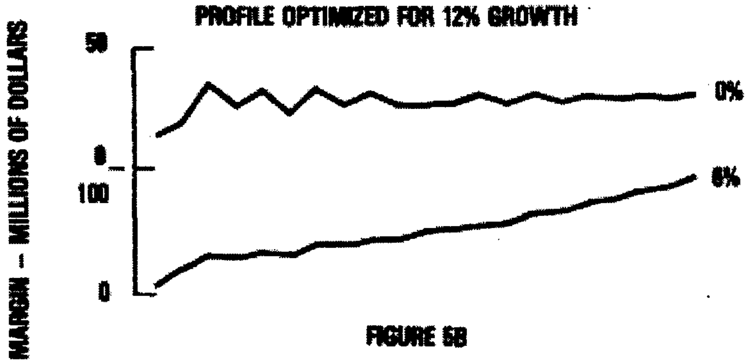


FIGURE 6B

PROFILE OPTIMIZED FOR 24% GROWTH

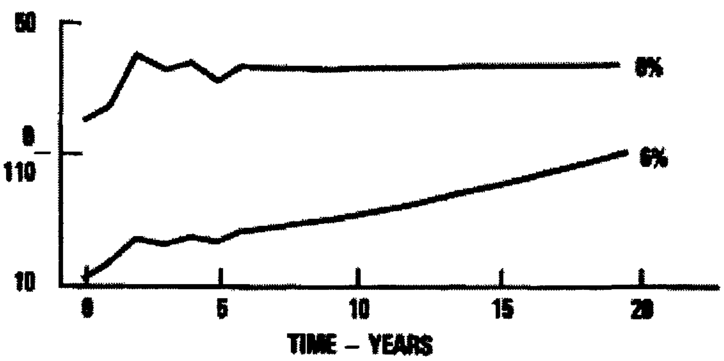
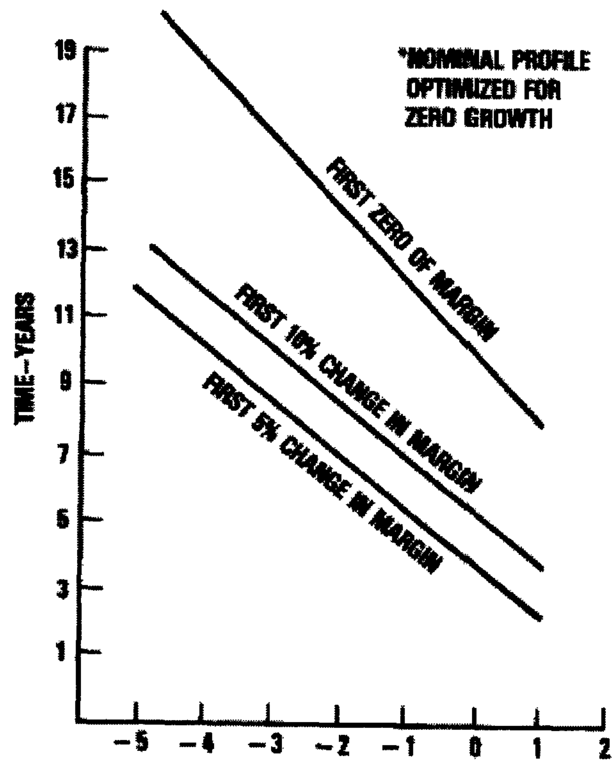


FIGURE 6C

TIME FOR MARGIN TO REACH INSTABILITY
VS
CHANGE IN PEAK VALUE OF PROFILE



PERCENT CHANGE OF PEAK VALUE FROM NOMINAL PROFILE (USING BASE 2)

FIGURE 6

MARGIN STABILITY

GROWTH RATE AT WHICH PROFILE WAS RUN	GROWTH RATE AT WHICH PROFILE PRODUCED OPTIMAL MARGIN				
	0%	6%	12%	24%	48%
0%	GOOD*	POOR	FAIR	GOOD	GOOD
6%	POOR	GOOD	GOOD	GOOD	GOOD
12%	POOR	FAIR	GOOD	GOOD	GOOD

THE ELEMENTS IN THE MATRIX DESCRIBE THE STABILITY OF THE MARGIN.

*THIS APPEARS TO BE A VERY UNSTABLE 'OPTIMUM'. WHEN THIS PROFILE WAS RUN AT − 1%, + .375% GROWTH RATE, VERY UNSTABLE MARGINS RESULTED.

FIGURE 7

PROJECTED AND ACTUAL MARGINS
VS
FISCAL YEAR

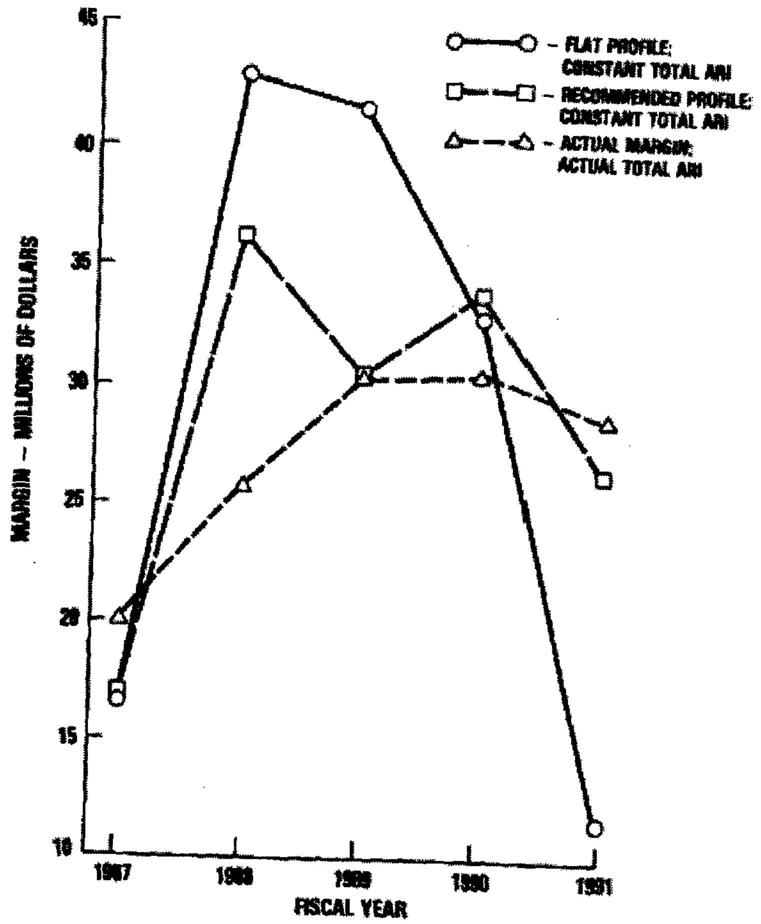


FIGURE 8

MARGIN/TOTAL ARI FUNDS RATIO
VS
FISCAL YEAR

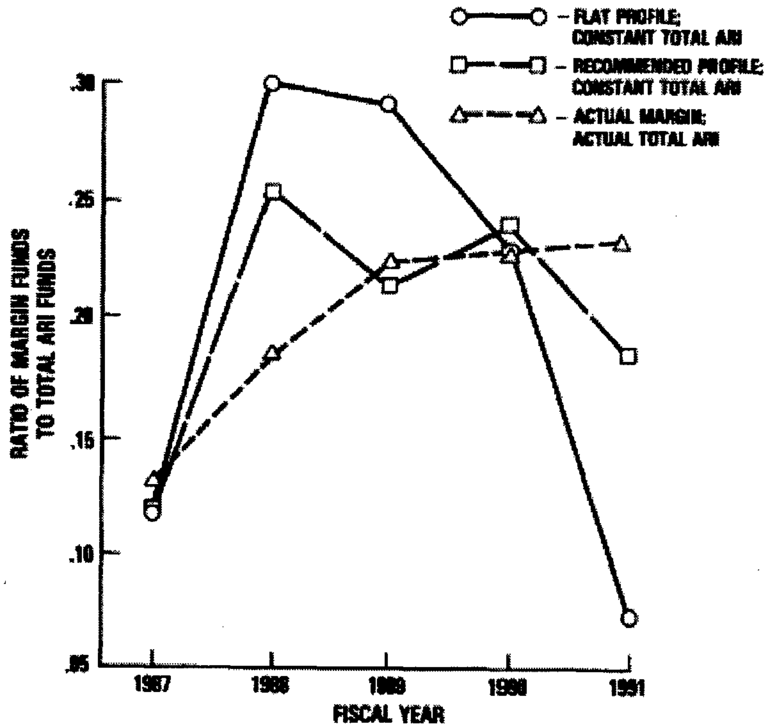


FIGURE 9

APPENDIX 2 - COMPUTATION OF IMPROVED FUNDING PROFILES FOR WINNING RESEARCH OPTIONS USING GINO

APPENDIX 2

COMPUTATION OF IMPROVED FUNDING PROFILES FOR WINNING ROs USING GINO

RESEARCH OPTION	FY90 $K	FY91 $K	FY92 $K	FY93 $K	FY94 $K	SUM $K
1.MAGNETOELECTRONIC MATERIALS						
MANDATED PROFILE	950	1330	1140	798	285	4503
DESIRED PROFILE	1100	1200	1100	800	303	4503
COMPUTED PROFILE	1110	1291	1081	773	247	4502
ABSVAL (MANDATED - DESIRED)	150	130	40	2	18	340
ABSVAL (COMPUTED - DESIRED)	10	91	19	27	56	203
2.IR MATERIALS						
MANDATED PROFILE	1530	2142	1836	1264	540	7312
DESIRED PROFILE	1380	2000	1978	1264	690	7312
COMPUTED PROFILE	1413	2265	1940	1207	488	7313
ABSVAL (MANDATED - DESIRED)	150	142	142	0	150	584
ABSVAL (COMPUTED - DESIRED)	33	265	38	57	202	595
3.METAL-ION BIOSENSORS						
MANDATED PROFILE	1898	2657	2277	1595	569	8996
DESIRED PROFILE	1400	2100	2400	2000	1096	8996
COMPUTED PROFILE	1469	2484	2391	1928	724	8996
ABSVAL (MANDATED - DESIRED)	498	557	123	405	527	2110
ABSVAL (COMPUTED - DESIRED)	69	384	9	72	372	906
4.PINS						
MANDATED PROFILE	2000	2806	2394	1688	575	9463
DESIRED PROFILE	1875	2500	2625	1563	900	9463
COMPUTED PROFILE	1935	2930	2563	1475	561	9464
ABSVAL (MANDATED - DESIRED)	125	306	231	125	325	1112
ABSVAL (COMPUTED - DESIRED)	60	430	62	88	339	979
5.NON-FREEZING COLD INJURY						
MANDATED PROFILE	500	700	600	420	150	2370
DESIRED PROFILE	700	620	550	300	200	2370
COMPUTED PROFILE	704	645	545	295	181	2370
ABSVAL (MANDATED - DESIRED)	200	80	50	120	50	500
ABSVAL (COMPUTED - DESIRED)	4	25	5	5	19	58
6.ARCTIC LEAD DYNAMICS						

MANDATED PROFILE	2700	3780	3240	2268	810	12798
DESIRED PROFILE	2700	3240	3780	2268	810	12798
COMPUTED PROFILE	2784	3957	3608	2063	387	12799
ABSVAL (MANDATED - DESIRED)	0	540	540	0	0	1080
ABSVAL (COMPUTED - DESIRED)	84	717	172	205	423	1601
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7.NONLINEAR SHIP MOTIONS						
MANDATED PROFILE	950	1330	1140	798	285	4503
DESIRED PROFILE	950	1230	1040	800	480	4500
COMPUTED PROFILE	965	1332	1029	779	394	4499
ABSVAL (MANDATED - DESIRED)	0	100	100	2	195	397
ABSVAL (COMPUTED - DESIRED)	15	102	11	21	86	235
8.ODORANT DISCRIMINATION						
MANDATED PROFILE	998	1398	1198	838	300	4732
DESIRED PROFILE	1049	1275	1425	883	100	4732
COMPUTED PROFILE	1051	1367	1388	846	80	4732
ABSVAL (MANDATED - DESIRED)	51	123	227	45	200	646
ABSVAL (COMPUTED - DESIRED)	2	92	37	37	20	188
9.PSEUDOMORPHIC STRUCTURES						
MANDATED PROFILE	1400	1960	1680	1176	420	6636
DESIRED PROFILE	1327	1460	1460	1460	929	6636
COMPUTED PROFILE	1382	1663	1462	1429	701	6637
ABSVAL (MANDATED - DESIRED)	73	500	220	284	509	1586
ABSVAL (COMPUTED - DESIRED)	55	203	2	31	228	519
10.VORTEX SHEDDING/WAKES						
MANDATED PROFILE	1100	1540	1320	920	330	5210
DESIRED PROFILE	1100	1400	1320	920	470	5210
COMPUTED PROFILE	1117	1531	1301	889	372	5210
ABSVAL (MANDATED - DESIRED)	0	140	0	0	140	280
ABSVAL (COMPUTED - DESIRED)	17	131	19	31	98	296
11.OCEAN CONVECTION/SUBDUCTION						
MANDATED PROFILE	2553	3574	2964	2145	766	12002
DESIRED PROFILE	2553	3000	3000	2400	1049	12002
COMPUTED PROFILE	2657	3658	2913	2227	548	12003
ABSVAL (MANDATED - DESIRED)	0	574	36	255	283	1148
ABSVAL (COMPUTED - DESIRED)	104	658	87	173	501	1523
12.STRATOCUMULUS TRANS IN MPBL						
MANDATED PROFILE	1900	2660	2220	1596	570	8946
DESIRED PROFILE	1900	2300	2200	1600	946	8946
COMPUTED PROFILE	1966	2685	2161	1521	613	8946
ABSVAL (MANDATED - DESIRED)	0	360	20	4	376	760
ABSVAL (COMPUTED - DESIRED)	66	385	39	79	333	902

13.DAMPING MATERIALS						
MANDATED PROFILE	775	1085	930	651	233	3674
DESIRED PROFILE	600	850	850	800	574	3674
COMPUTED PROFILE	615	917	853	792	497	3674
ABSVAL (MANDATED - DESIRED)	175	235	80	149	341	980
ABSVAL (COMPUTED - DESIRED)	15	67	3	8	77	170
14.POLYMERS FOR ELECTRONICS						
MANDATED PROFILE	800	1120	960	672	240	3792
DESIRED PROFILE	800	960	960	672	400	3792
COMPUTED PROFILE	812	1028	953	658	340	3791
ABSVAL (MANDATED - DESIRED)	0	160	0	0	160	320
ABSVAL (COMPUTED - DESIRED)	12	68	7	14	60	161
15.SUBBOTTOM REVERBERATION						
MANDATED PROFILE	2257	3160	2708	1896	677	10698
DESIRED PROFILE	2225	2895	2630	1966	982	10698
COMPUTED PROFILE	2299	3452	2553	1833	561	10698
ABSVAL (MANDATED - DESIRED)	32	265	78	70	305	750
ABSVAL (COMPUTED - DESIRED)	74	557	77	133	421	1262
TOTAL SUMMATIONS						
MANDATED PROFILE	22311	31242	26607	18725	6750	105635
DESIRED PROFILE	21659	27030	27318	19696	9929	105632
COMPUTED PROFILE	22279	31205	26741	18715	6694	105634
ABSVAL (MANDATED - DESIRED)	1454	4212	1887	1461	3579	12593
ABSVAL (COMPUTED - DESIRED)	620	4175	587	981	3235	9598